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The BART Impact Program is a comprehensive, policy-oriented study and evaluation of the impacts of the San Francisco Bay Area's new rapid transit system (BART).

The program is being conducted by the Metropolitan Transportation Commission, a nine-county regional agency established by state law in 1970.

The program is financed by the U. S. Department of Transportation, the U. S. Department of Housing and Urban Development, the National Science Foundation, and the California Department of Transportation. Management of the Federally-funded portion of the program is vested in the U. S. Department of Transportation.

The BART Impact Program covers the entire range of potential rapid transit impacts, including impacts on traffic flow, travel behavior, land use and urban development, the environment, the regional economy, social institutions and life styles, and public policy. The incidence of these impacts on population groups, local areas, and economic sectors will be measured and analyzed. The benefits of BART, and their distribution, will be weighed against the negative impacts and costs of the system in an objective evaluation of the contribution that the rapid transit investment makes toward meeting the needs and objectives of this metropolitan area and all of its people.

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PRELIMINARY FINDINGS
SOUND

THE ENVIRONMENT PROJECT

BART IMPACT PROGRAM

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PRELIMINARY FINDINGS

SOUND

INTRODUCTION & SUMMARY OF FINDINGS

This report presents early aspects of a measurement and analysis program currently underway to assess the acoustic impact of the Bay Area Rapid Transit System (BART) on its environment. In particular, it covers findings relative to simultaneous recordings of sound levels taken on-board BART cars and at wayside positions adjacent to the BART track. These findings are offered as tentative conclusions reached during the initial phases of the sound analysis program. These early findings will be combined with adjacent community non-BART related sound levels in the final report. The comparison of BART generated sound levels modified by physical and perceived characteristics will be used in the assessment of BART acoustic impact on its surroundings.

Analysis of the data obtained during the measurement program indicated a correlation could be made between the on-board measured sound levels and those measured at the wayside; and further, there is a direct correlation between train speed, track configuration and sound level. From the data reduction of the on-board measurements a number of findings have emerged. These relate to consistency of noise levels for a particular track type (aerial or tie-and-ballast track), a consistent difference between aerial and tie-and-ballast, the measured relationship between train speed and sound level and the identification of a number of irregularities in the system sound levels. Details on these findings plus the methodology for the on-board measurement program and a generalized BART wayside sound profile are all part of these early findings on BART sound characteristics.

The primary goal of this program has been to assess the acoustic impact of the whole BART system on the communities which it serves. While the level of effort that has been allocated to this task is adequate to perform such a survey, the results and conclusions should not be misinterpreted. While the program has included study of individual elements, the development of information concerning the acoustic impact of the system as a whole has been given equal priority.

BART SYSTEM SOUND LEVEL PROFILE

Assessment of BART's acoustic impact on its surroundings requires knowledge of the degree to which BART-generated sounds protrude above the existing community ambient around the BART system. Knowledge of both the sound levels generated by the BART system and the ambient sound levels in the existing community are essential to such an assessment. The initial phase of this measurement and analysis program has been directed at obtaining a system-wide description of the sound levels produced by BART.

The primary method of measurement to obtain a quantifying description of BART-generated sound has been measurement of BART train pass-bys at the wayside under various track configurations and train speeds. A series of on-board train measurements which provide a means of obtaining a relative grading of the entire BART system have been used as a guideline for selecting "typical" wayside measurement positions.

The on-board measurements have been used to develop a sound level profile of the BART system. In order to develop the profile, a correlation between on-board and wayside sound level has been determined. Using the correlation and the measured relationship between train speed and sound level, system-wide wayside sound levels were computed for BART vehicles operating at design speed.

Development of On-Board/Wayside Sound Level Correlation

Sound levels on-board BART cars[*] have been recorded for at least two complete circuits of each of the four BART lines. In addition, a series of simultaneous on-board and wayside sound level recordings were made between Walnut Creek and Pleasant Hill stations. The sound level on-board the car in each case was found to be 2-5 dB(A) lower than the simultaneous wayside sound level, depending on track configuration. Specifically, the interior sound levels are 2 dB(A) lower than the wayside sound levels (at a distance of 50' (15m) from the track centerline) when the train is on tie-and-ballast track. When the train is operating on an aerial structure, one may add 5 dB(A) to the interior sound level to obtain the wayside sound level. These findings are insensitive to speed. That is, the 2 and 5 dB(A) interior/exterior sound level differences apply whether the train is operating at 40 mph or 80 mph.

The initial test for determining a relationship between on-board sound levels and wayside sound levels consisted of a series of measurements both on-board BART trains and at the wayside between Pleasant Hill and Walnut Creek stations. During this series of tests, measurements were conducted on eight different cars. A total of 11 pass-bys of the wayside measurement positions were made. Two separate pass-bys were recorded on three of the cars (runs 1 & 7, 3 & 9, and 4 & 10).

Car speed (obtained from the digital speed indicator located in the operator's cab in the lead car) and position (BART system mile post markers and visual sitings of the wayside measurement locations) were annotated by voice on the second channel of the on-board recording system. The data tapes from the Pleasant Hill/Walnut Creek runs (both the on-board and wayside) were reduced using an

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[*] The microphone position for all on-board recording was at a distance of 1.5' (0.5m) from the bottom center of the front out-board door in the lead car of the train.

A-weighting network and graphic level recording system adjusted to simulate the fast response of a sound level meter.* Using the information on the annotation channel, the simultaneous sound levels on-board the train and at the wayside were determined. A model of the train, as a line of uncorrelated point sources - per Remington[1], was used to normalize all wayside sound levels to a distance of 50' (15m) from the track centerline and a six car train.** The on-board and wayside levels determined from these 11 runs are shown in Table 1.

From Table 1 it can be seen that the wayside sound levels were consistently 5 and 2 dB(A) higher than the simultaneous on-board measurements for measurement location #1 (track on aerial structure) and location #2 (track on tie-and-ballast), respectively. It should be noted that the sound levels indicated on Table 1 are as recorded and not normalized to a constant speed. For this reason, comparison of sound levels between runs is not generally applicable. Subsequent measurements on-board over the entire system and at several wayside locations (discussed later in this report) have provided additional data supporting this straightforward on-board/wayside sound level correlation for the BART system.

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*See Appendix for equipment list and measurement and analysis systems schematic diagrams.

** The difference (ΔL) between a measured sound level and the normalized sound level for the BART system may be found using the following equation:

$$\Delta L = 10 \log_{10} \left[\frac{34.4}{d} \times \tan^{-1}\left(\frac{35N}{d} \right) \right] \quad \mathrm{dB(A)}$$

Where: d = Perpendicular distance from measurement point to the train in feet

N = Number of cars in train

TABLE 1

SUMMARY OF DATA FROM ON-BOARD/WAYSIDE MEASUREMENTS BETWEEN PLEASANT HILL & WALNUT CREEK STATIONS

RUN #	DIRECTION*	L_{max_1}	L_{max_2}	L_{PT_1}	L_{PT_2}	$(L_{max} - L_{PT})$ Position 1 Aerial NB	$(L_{max} - L_{PT})$ Position 1 Aerial SB	$(L_{max} - L_{PT})$ Position 2 Tie & Ballast NB	$(L_{max} - L_{PT})$ Position 2 Tie & Ballast SB
1	NB	88	84	83	82	5		2	
2	SB	77	68	76	71		1		-3
3	NB	88	84	83	81	5		3	
4	SB	86	80	86	84		0		-4
5	NB	88	84	83	82	5		2	
6	SB	77	69	76	72		1		-3
7	NB	88	84	84	83	4		1	
8	SB	85	78	85	82		0		-4
9	NB	88	85	83	82	5		3	
10	SB	78	69	78	73		0		-4
11	NB	89	83	84	81	5		2	

L_{max_1}, L_{max_2} = Peak train pass-by sound levels** at Positions 1 and 2.

L_{PT_1} , L_{PT_2} = In-car sound levels as train passed measurement positions.

* NB = North Bound SB = South Bound

** Normalized to a distance of 50 feet from the track centerline for a six car train.

Relationship Between Sound Level and Train Speed

The sound level produced by a steel wheeled rail vehicle depends in large part on the speed at which the train is traveling. Normalizing the sound level produced by a BART train as it passes allows one to gain insight into the differences between different cars and between different segments of the system.

Previous studies (2-6) have indicated that the wayside sound levels due to rapid transit operations in general vary as the cube of the vehicle speed or as 30 times the logarithm to the base 10 of the vehicle speed. When a linear regression analysis was performed on the speed versus interior sound level data obtained between Pleasant Hill and Walnut Creek stations, a somewhat greater than expected dependence on speed was observed. Specifically, the on-board measured data indicate that the sound level varies as 38 times the logarithm of the train speed on tie-and-ballast track and 35 times the logarithm of the train speed on aerial track.

The rather small sample size (N=11) available for the Pleasant Hill - Walnut Creek runs together with differences suspected to exist between the individual cars in which measurements were conducted tends to reduce the significance of the higher than expected variation of sound level with train speed. Since the ability to accurately normalize the observed sound levels to a given speed was felt necessary for the program, an experiment to develop more accurate information concerning the relationship between train speed and sound level was devised.

A subsequent series of measurements consisted of the monitoring of the sound levels on an individual BART car over the entire length of each of the four system lines. Specifically, sound levels were monitored on a single car from Fremont to Richmond; the microphone was then moved to a car at the other end of the same train for the trip from Richmond back to Fremont. The pro-

cess was then repeated. In a similar manner, the on-car sound levels were monitored from the Daly City station to the Concord station and back. Analysis of the data taken during this portion of the measurement program has shown that the in-car sound levels vary as approximately 28 times the logarithm of the car speed for both tie-and-ballast and aerial track. The specific relationships determined from the regression analysis may be expressed as:

Tie-and-Ballast Track

$$Lp = 29 + 28 \log_{10} S \quad dB(A) \qquad \text{Equation (1)}$$

Aerial Track

$$Lp = 30.5 + 28 \log_{10} S \quad dB(A) \qquad \text{Equation (2)}$$

Where: Lp = On-board sound level in dB(A)
S = Train speed in miles per hour

Although the actual values computed from the data are given in the above equations, it is not the intent of this report to imply that the 28 $\log_{10}$ dependence on speed for the BART system differs significantly from the 30 $\log_{10}$ relationship normally found in the literature. In fact, the constants on the right side of Equations 1 and 2 may be adjusted in such a way that a 30 $\log_{10}$ relationship would yield results within 1 dB(A) of Equations 1 and 2 in the range of 40 to 80 mph.

These sound level versus speed relationships are consistent throughout the BART system. The coefficients determined for individual cars range from 27.2 to 28.9 while the standard deviation of the difference between the measured and calculated remained at approximately 1.0 dB. If one includes all the data for the six separate cars used for the system-wide measurements, the standard deviation of the difference between the computed and the measured sound levels increases to approximately 1.5 dB. This increased deviation between measured levels and the generalized speed relationship is attributable to the differences in levels generated by specific cars.

Such differences between cars could account for the greater than expected dependence on speed indicated by the wayside measurements between Pleasant Hill and Walnut Creek.

It is important to note that microphone location used during the on-board measurement program results in the recording of levels that are quite likely not representative of those encountered by passengers, either standing or seated. The microphone location was chosen by subjectively searching for a spot where wheel noise was most easily heard. Thus, it is inappropriate to consider the sound levels obtained from Equations 1 and 2 as typical of the sound levels encountered by BART passengers.

A feature unique to the BART system is the "wheel scraper" device which has been attached to some of the earlier BART cars as an element of the train control system. Although all cars used for the on-board measurement system did have these wheel scrapers installed, no specific quantitative evaluation of their contribution to the overall sound levels was performed. Qualitatively, the scrapers are occasionally audible at train speeds below 20 mph, but tend to emit less significant, very high frequency signals as the train speed increases.

Conversion of On-Board to Wayside Sound Levels

A sound level profile of the entire BART system has been developed using the on-board measured sound levels, the computed relationship between train speed and on-board sound levels, and the relationship between on-board sound levels and wayside sound levels. In developing the profile, the on-board measured sound levels were normalized to the design speed (in general 80 mph) for all segments of the BART system. This was accomplished using the 28 $\log_{10}$ relationship between speed and sound level. The normalized on-board levels were then corrected to wayside levels using the previously determined 2 and 5 dB(A) correction factors.

Adding the on-board to wayside correction terms to Equations 1 & 2, we obtain the following relationships for the wayside levels adjacent to tie-and-ballast track (L_T) and track on aerial structures (L_A):

$$L_T = 31 + 28 \log S \quad dB(A) \qquad \text{Equation (3)}$$

$$L_A = 36 + 28 \log S \quad dB(A) \qquad \text{Equation (4)}$$

Figure 1 illustrates an actual recording made on-board a BART car between two stations and the generalized wayside levels derived from the on-board measurements. A major difference between the illustrations in Figure 1 is that the horizontal axis of the top figure is time, while on the bottom figure this axis has been converted to position along the BART system.

Maps 1 through 5 in the Appendix at the end of this report illustrate the generalized wayside* sound level profiles for the entire BART system. We see that the sound levels increase as the trains pick up speed leaving the stations and, in general, plateau as the trains reach design speed. The plateau height may be seen to differ by some 5 dB(A), depending on whether the train is on tie-and-ballast track or on an aerial structure. Additionally, increases in the sound levels are observed at such points in the system as switches and curves. The sound level profiles on Maps 1 through 5 are based on the trains traveling at design speed (usually 80 mph) between stations and on an average value of acceleration in and out of the stations.

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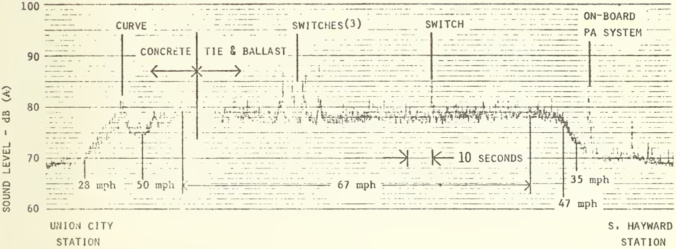
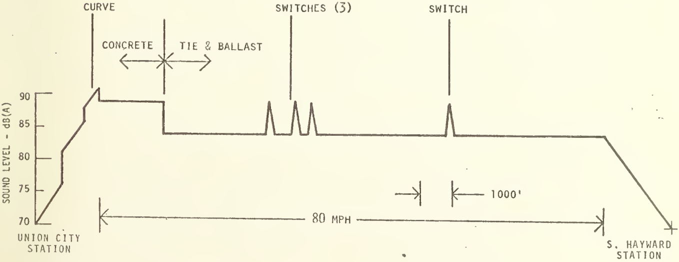
*Wayside, for the sound level profiles is defined as 50' from the centerline of the near track, with unobstructed line of sight to the track. The profiles represent a composite of both north and south bound lines.

FIGURE 1

ON-BOARD SOUND LEVEL MEASUREMENT AND GENERALIZED WAYSIDE SOUND LEVEL PROFILE





Variation in Sound Levels as a Function of Track Type

Examination of the levels recorded throughout the system indicated that on straight tie-and-ballast track, in the absence of switches or other irregularities in the track system, the on-board monitored sound levels were very consistent. The mean wayside sound level for tie-and-ballast track (normalized to a distance of 50' and a train speed of 80 mph) was found to be 84 dB(A). The standard deviation of the sound levels about the normalized mean on tie-and-ballast track throughout the entire system was approximately 1 dB(A). The normalized mean sound level for trains on aerial structure was found to be 89 dB(A) with a standard deviation of 1 dB(A). As will be shown in a later section, these on-board developed sound levels are consistent with those actually measured at the wayside for a number of train pass-bys.

WAYSIDE MEASUREMENTS

Using the results outlined in the previous section, sites have been selected along the system to monitor sound levels of BART train pass-bys. These sites have been selected so that both the plateau height of the sound level profile (straight tie-and-ballast or aerial structure track) and the effect of system irregularities such as switches may be evaluated.

At this time, sufficient data are available to present findings on wayside sound levels adjacent to tie-and-ballast track, track on aerial structures, and switches on tie-and-ballast track as reported below. In the final report, other irregularities such as switches on aerial structures, curves and tunnel entrances and exits will be fully discussed.

Tie-and-Ballast Train Pass-Bys

The wayside sound levels generated by BART trains on level tie-and-ballast track at-grade were monitored over a period which included some 25 train pass-bys in each direction between Union City and Fremont stations. The sound levels generated by the trains as they passed the measurement location were recorded on magnetic tape, while the time required for the train to pass the measurement position and the number of cars on the train were recorded on a second channel of the same tape recorder. Thus, the noise level generated by the train as well as train length and speed were obtained from reduction of the recordings.

Using this information, a linear regression was performed on the sound levels measured versus the logarithm of the train speed. The results of the analysis indicated that the wayside sound level varied as 38.3 $\log_{10}$ of the train speed. Figure 2 is the scatter diagram* for the data obtained during the tie-and-ballast track wayside measurement. As may be observed from the diagram, the trains tended to pass the measurement position at one of three speeds: 49, 68 or 80 miles per hour. The scatter in the measured sound level at each speed is taken to indicate differences in the sound levels generated by different cars (and trains). The fact that the computed variation of sound level with speed is greater for the wayside measurements than the on-board measurements may be attributed to the differences between individual cars.

The rather large 90% confidence interval around the coefficient (± 11.0) suggests that a 28 log relationship as determined from the on-board measurements may also be valid. When a force-fit of a 28 log relationship through the mean of the data is performed,

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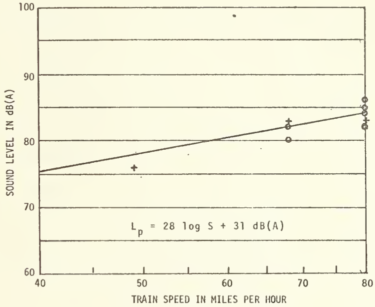
*The circles represent multiple data points and the crosses represent single data points on Figure 2.

FIGURE 2

OBSERVED WAYSIDE SOUND LEVELS AS A FUNCTION OF BART TRAIN SPEED FOR TRAIN ON TIE AND BALLAST TRACK



the standard deviation shows very little increase (1.53 dB(A) versus 1.24 dB(A)). A most significant fact, however, is that the measured wayside levels (L_{TW}) from the 25 pass-bys in each direction (normalized to a six car train at 50') now follow the relationship:

$$L_{TW} = 31 + 28 \log S \quad \text{dB(A)} \qquad \text{Equation (5)}$$

Comparison of Equations 3 and 5 reveals that the sound level/speed relationships derived from the on-board and wayside measurements are identical. Further, if we normalize the relationship to a speed of 15 mph and use a slope of 30 $\log_{10}$ speed as most often found in the literature we obtain:

$$L_{TW} = 62 + 30 \log \frac{S}{15} \quad \text{dB(A)} \qquad \text{Equation (6)}$$

This relationship is within 2 dB(A) of the relationship for "good" Rapid Transit Systems determined by Remington, et al.[7]

Track on Aerial Structures

Figure 3 illustrates the scattergram of the data obtained at a wayside position adjacent to BART track on an aerial structure between Union City and Fremont stations. In addition, we have indicated a 28 log speed relationship which has been force-fitted through the mean of the data. As with the previous scattergram, the crosses represent single data points, while the circles represent multiple data points. It is of special significance that the point on the scattergram corresponding to 80 mph and 89 dB(A), represents seven individual measurements. As with the measurements made adjacent to tie-and-ballast track, those made adjacent to the track on aerial structures result in a relationship between sound level and train speed identical to that determined from the on-board measurements when a force-fit is made to the 28 log of speed relationship. This relationship for the wayside sound level adjacent to track on aerial structures (L_{AW}) may be expressed as:

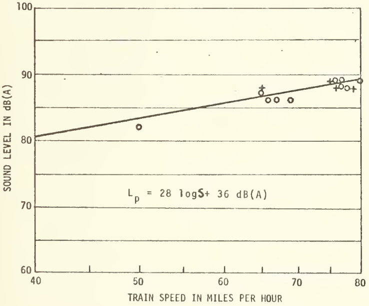
$$L_{AW} = 36 + 28 \log S \qquad \text{dB(A)} \qquad \text{Equation (7)}$$

Or using the format of Remington:

$$L_{AW} = 67 + 30 \log \frac{S}{15} \qquad \text{dB(A)} \qquad \text{Equation (8)}$$

FIGURE 3

OBSERVED WAYSIDE SOUND LEVELS AS A FUNCTION OF BART TRAIN SPEED FOR TRAIN ON AERIAL STRUCTURE

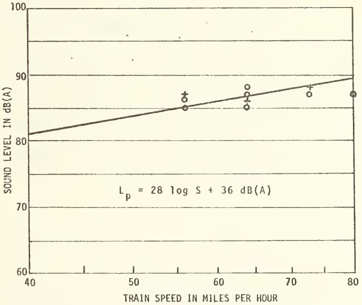


Switch on Tie-and-Ballast Track

In Figure 4 we present the scattergram of the data obtained at the wayside near a switch on tie-and-ballast track. Also indicated is the regression line developed from the measured data. The regression analysis yielded a 30 log dependence of sound level on speed, with a rather small confidence interval (90%, ± 6) on the coefficient. In light of the rather large differences between individual cars and trains seen for straight track, this tightening of the interval around the speed coefficient seems to indicate that the noise produced by switches is somewhat independent of the cars. This result is in accordance with the recent findings of Bender and Remington[8] which indicates that rail rather than wheel radiated noise may well dominate at the wayside.

FIGURE 4

OBSERVED SOUND LEVELS AT A DISTANCE OF 50' FROM A SWITCH ON TIE-AND-BALLAST TRACK AS A FUNCTION OF BART TRAIN SPEED



The mean height of the sound level versus speed relationship is approximately 5 dB(A) above that determined for straight tie-and-ballast track. Put another way, this means that the wayside sound levels adjacent to switches were approximately 5 dB(A) higher than adjacent to straight tie-and-ballast track. It is of interest to note that the 5 dB(A) increase in sound level is also observed on-board the train as it passed over a switch.

Force-fitting the data to the 28 $\log_{10}$ slope used previously, the relationship between wayside sound level near a switch (L_{SW}) and train speed may be expressed by:

$$L_{SW} = 35 + 28 \log S \qquad \text{dB(A)} \qquad \text{Equation (9)}$$

One may observe that this equation is identical to that determined for straight track on aerial structures. Thus, while restricted

to localized areas, switches on tie-and-ballast track tend to generate sound levels of the same magnitude as track on aerial structures. If the equation is modified to the form suggested by Remington:

$$L_{SW} = 67 + 30 \log \frac{S}{15} \quad \text{dB(A)} \qquad \text{Equation (10)}$$

we find that this result is in accordance with Remington's data for jointed track systems. The implication here is that switches, when on tie-and-ballast track, do not raise the BART wayside sound levels above those that would be expected for "normal" jointed track.

PRELIMINARY CONCLUSIONS

The initial portion of the measurement program which was aimed at obtaining a relationship between on-board measured sound levels and wayside sound levels in order to facilitate describing sound levels as they exist over the entire system, and to identify specific sites for indepth study, has been quite promising. Most important is the fact that the relationships derived from the on-board measurement program for wayside sound levels are identical to those obtained from actual measurement at the wayside. The three system configurations thus far examined (tie-and-ballast, switch on tie-and-ballast, and track on aerial structures) have indicated that there is indeed a direct correlation between train speed, track configuration, and sound level.

An important element has been the fact that through the on-board measurement program it was possible to determine the actual dependence of sound level on train speed independent of variables between cars. By normalizing the sound levels as measured to a constant speed, we are able to eliminate speed as a variable in

our wayside measurements, thereby allowing an analysis of the variance in sound level between individual trains on the system. It is of specific interest that the variation between cars is rather small. The standard deviation of approximately 1.5 decibels indicates that 90% of the vehicles generate wayside sound levels within a 5 dB(A) band centered about the relationships indicated on Figures 2 through 4.

Finally, from the analysis it has been determined that the normalized wayside sound levels for the BART system operating at design speed are 84 and 89 dB(A) for the tie-and-ballast track and for track on aerial structures, respectively. Such sound levels are equivalent to the peak sound levels produced by trucks, buses, and motorcycles on urban streets.(9,10)

Review of two reports containing information on the Chicago Transit Authority Line (9) and the Metropolitan Boston Transit Authority Line (11) reveals a significant difference between the wayside sound levels produced by these older systems and those produced by BART. The wayside levels adjacent to aerial structures are reported to be 2 and 12 dB(A) higher for the Boston and Chicago systems than for BART. The at-grade portions are reported to be 2 - 6 dB(A) higher respectively. These differences take on even greater importance when one considers the data from the Boston and Chicago systems were obtained at vehicle speeds significantly less than 80 mph as has been the case for BART.

As indicated at the beginning of this report these early findings relative to BART will be combined with measurements of adjacent community ambient sound levels, and both modified by physical characteristics and perceived characteristics, to arrive at an assessment of BART acoustic impact on its surroundings.

REFERENCES

1 Remington, P.J., et al., "Wheel/Rail Noise and Vibration Control," prepared for the U.S. Department of Transportation, (May, 1974).

2 Bender, E.K.; Ely, R.A.; Remington, P.J. and Rudd, M.J., "Railroad Environmental Noise: A State of the Art Assessment," prepared by the Environmental Studies Divn., Association of American Railroads, BBN Report No. 2709, (January, 1974).

3 Bender, E.K., and Remington, P.J., "The Influence of Rails on Train Noise," Journal of Sound and Vibration, (1974) 37(3), pp. 321-334.

4 Manning, J.E.; Cann, R.G., and Fredberg, J.J., "Prediction and Control of Rail Transit Noise and Vibration: A State of the Art Assessment," prepared for the U.S. Department of Transportation, (July, 1974).

5 U.S. Environmental Protection Agency, "Transportation Noise and Noise from Equipment Powered by Internal Combustion Engines," (December, 1971).

6 Wilson, Ihrig & Associates, Inc., "Noise and Vibration Characteristics of High Speed Transit Vehicles," prepared for the U.S. Department of Transportation, (June, 1974).

7 Remington, P.J., et al., "Wheel/Rail Noise and Vibration Control," prepared for the U.S. Department of Transportation, (May, 1974).

8 Bender, E.K., and Remington, P.J., "The Influence of Rails on Train Noise," Journal of Sound and Vibration, (1974) 37 (3), pp. 321-334.

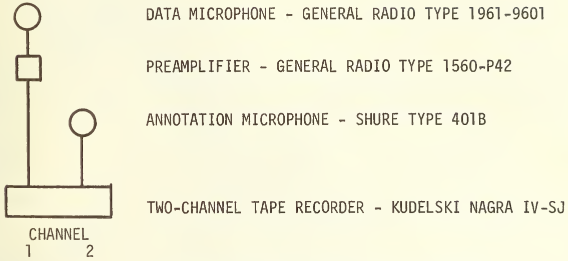
9 Blazier, W.E., Jr., et al.; "Chicago Urban Noise Study: Noise in the Urban Environment," prepared for the City of Chicago Department of Environmental Control (Nov., 1970).

10 Porter, M.A., et al; "Noise in San Francisco," prepared for the City of San Francisco Department of Public Works, (June, 1974).

11 Kurzweil, L.G., et al.; "Noise Assessment and Abatement in Rapid Transit Systems: Report on the MBTA Pilot Study" prepared for U.S. Department of Transportation (August, 1974).

APPENDIX

MEASUREMENT AND ANALYSIS SYSTEMS
BART ON-BOARD AND WAYSIDE MEASUREMENTS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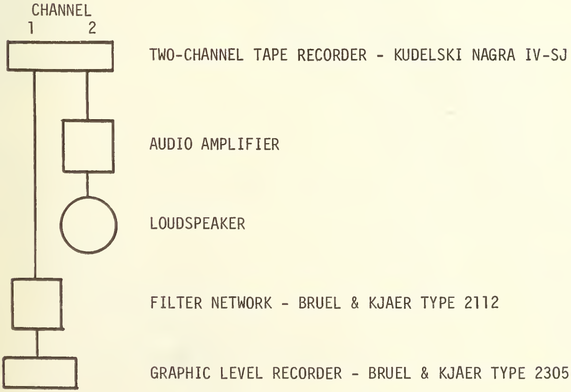
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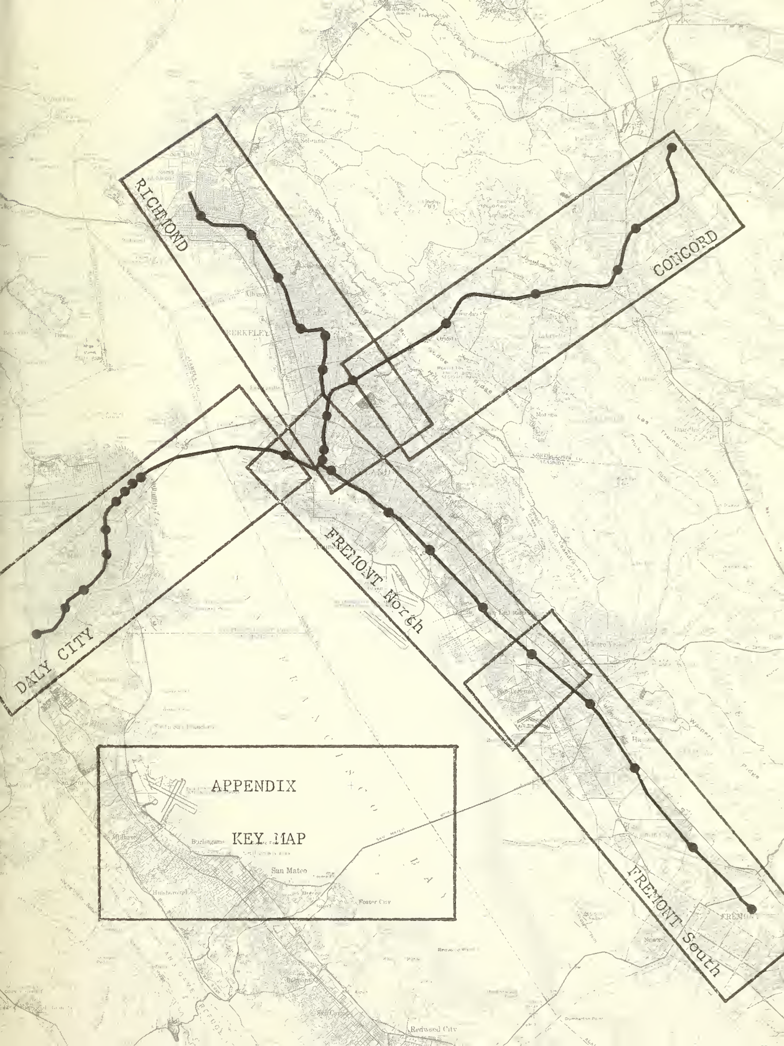
1
2
TWO-CHANNEL TAPE RECORDER - KUDELSKI NAGRA IV-SJ
AUDIO AMPLIFIER
LOUDSPEAKER
FILTER NETWORK - BRUEL & KJAER TYPE 2112
GRAPHIC LEVEL RECORDER - BRUEL & KJAER TYPE 2305

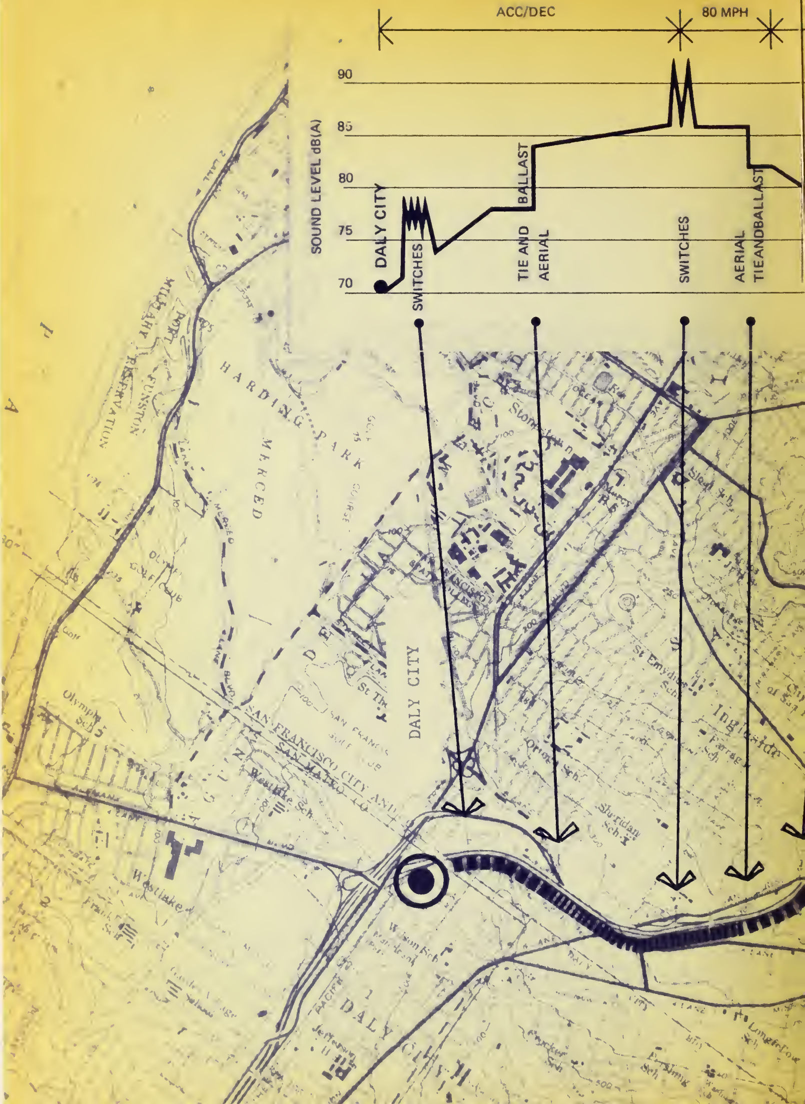
DATA ANALYSIS SYSTEM



APPENDIX

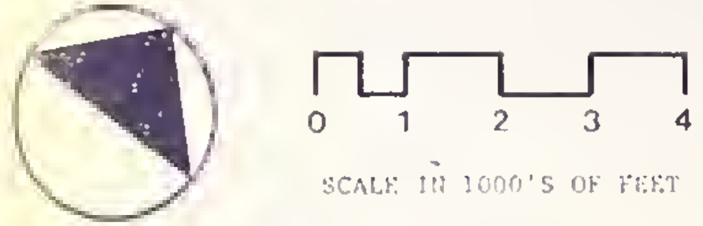
KEY MAP

ACC/DEC
80 MPH
ACC/DEC
90
85
80
75
70
SOUND LEVEL dB(A)
DALY CITY
SWITCHES
TIE AND AERIAL
BALLAST
SWITCHES
AERIAL
TIE AND BALLAST
TUNNEL
TIE AND BALLAST
TUNNEL
GLEN PARK
80 MPH
ACC/DEC
90
80
70
SOUND LEVEL dB(A)
TRANSIT TUBE
AERIAL
SWITCHES
OAKLAND
SAN FRANCISCO
DALY CITY
GLEN PARK
24TH STREET
16TH STREET
CIVIC CENTER
POWELL STREET
MONTGOMERY ST.
EMBARCADERO
TREASURE ISLAND
YERBA BUENA ISLAND
SAN FRANCISCO BAY
ALAMEDA NAVAL AIR STATION
OAKLAND WEST
OAKLAND


ACC/DEC
80 MPH
90
85
80
75
70
SOUND LEVEL dB(A)
DALY CITY
SWITCHES
TIE AND AERIAL
BALLAST
SWITCHES
AERIAL
TIE AND BALLAST
FORT FUNSTON MILITARY RESERVATION
HARDING PARK
MERCED
OLYMPIC GOLF CLUB
Olympic Sch
DALY CITY
SAN FRANCISCO CITY AND SAN MATEO CO
Westlake Sch
Westlake
Stonestown
St Emydius Sch
Ingleside
Sheridan Sch
Farragut Sch
DALY CITY
Jefferson Sch
Longfellow Sch
Pershing Sch

CONCORD LINE

ENERALIZED BART WAYSIDE
OUND PROFILE



SCALE IN 1000'S OF FEET

THE ENVIRONMENT PROJECT
BART IMPACT PROGRAM
FEBRUARY 1975

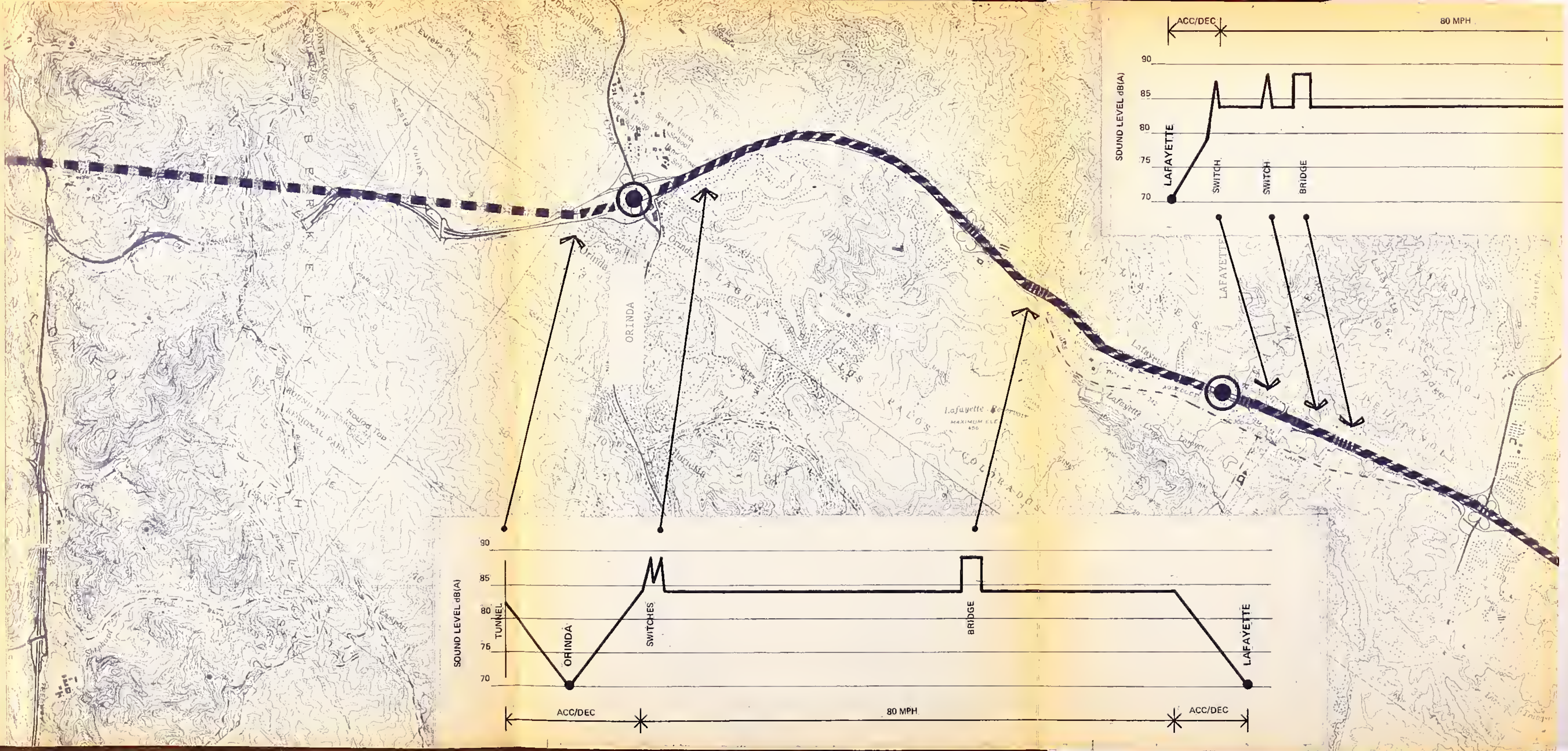
EGEND

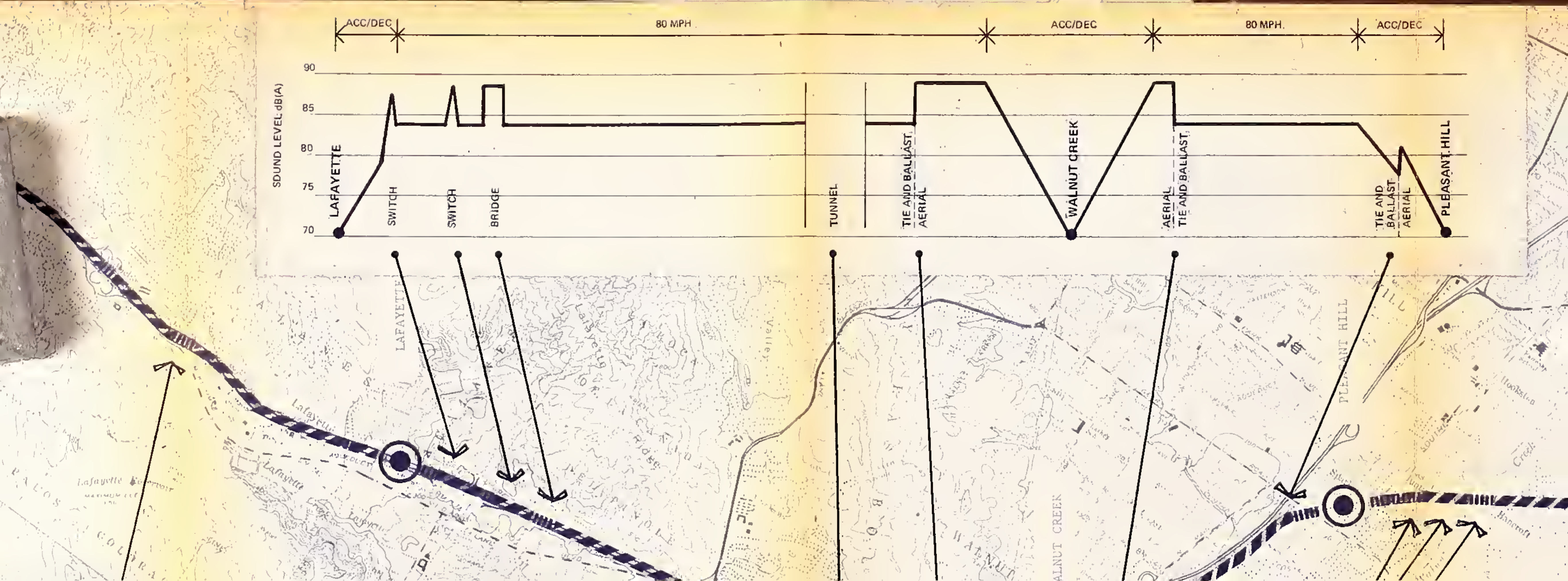
ESE GENERALIZED BART
AYSIDE SOUND PROFILES:

- ARE COMPOSITS OF SOUND LEVELS GENERATED BY TRAIN MOVEMENT IN BOTH DIRECTIONS.
- ARE NORMALIZED FROM THE SOUND MEASUREMENTS AT ACTUAL TRAIN SPEEDS TO THE PROJECTED SOUND LEVEL AT THE MAXIMUM DESIGN SPEED FOR EACH TRACK SEGMENT.
- GIVE SOUND LEVELS FOR THE ENTIRE BART SYSTEM, AND IDENTIFY SPECIFIC SYSTEM FEATURES THAT PRODUCE MEASUREABLE SOUND CHANGES.

BART CONFIGURATION AND FACILITIES:

SUBWAY LINE	■ ■ ■
AERIAL LINE	❙❙❙❙❙❙❙❙❙❙❙❙
LINE AT GRADE	■■■■■■■
LINE ON BERM	▰▰▰▰
ABOVE GRADE STATION WITH PARKING LOT	◉
SUBWAY STATION WITHOUT PARKING LOT	○
SUBWAY STATION WITH PARKING LOT	◎
MAINTENANCE/STORAGE YARD	▨




ACC/DEC
80 MPH
ACC/DEC
80 MPH
ACC/DEC
SOUND LEVEL dB(A)
90
85
80
75
70
LAFAYETTE
SWITCH
SWITCH
BRIDGE
TUNNEL
TIE AND BALLAST
AERIAL
WALNUT CREEK
AERIAL
TIE AND BALLAST
TIE AND BALLAST
AERIAL
PLEASANT HILL
LAFAYETTE
Lafayette Reservoir
Lafayette
Valley
Ridge
WALNUT CREEK
PLEASANT HILL
Hookston
Creek
Bancroft

RICHMOND LINE

GENERALIZED BART WAYSIDE SOUND PROFILE

0 1 2 3 4

SCALE IN 1000'S OF FEET

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LEGEND

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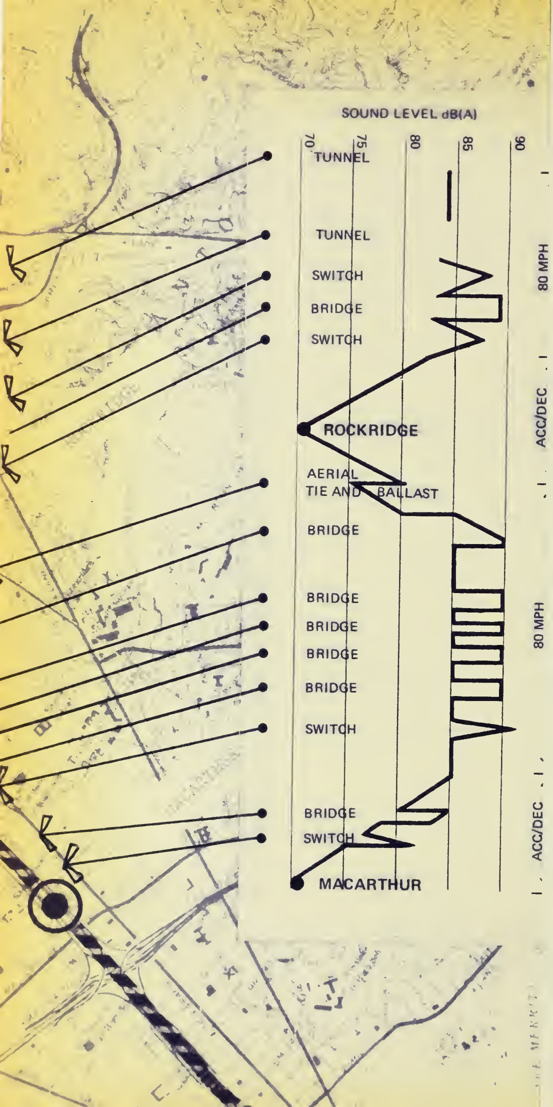
BART CONFIGURATION AND FACILITIES	
SUBWAY LINE	▬ ▬ ▬
AERIAL LINE	❙❙❙❙❙❙❙❙❙❙❙❙
LINE AT GRADE	▮▮▮▮▮▮▮
LINE ON BERM	▰▰▰▰
ABOVE GRADE STATION WITH PARKING LOT	◉
SUBWAY STATION WITHOUT PARKING LOT	○
SUBWAY STATION WITH PARKING LOT	◎
MAINTENANCE/STORAGE YARD	▨

80 MPH
ACC/DEC
80 MPH
ACC/DEC
80 MPH
ACC/DEC
80 MPH
ACC/DEC
55 MPH
ACC/DEC
AERIAL
TIE AND BALLAST
TIE AND BALLAST
AERIAL
EL CERRITO DEL NORTE
SWITCHES
EL CERRITO PLAZA
SOUND BARRIERS
AERIAL
TUNNEL
NORTH BERKELEY
BERKELEY
ASHBY
TUNNEL
AERIAL
SWITCH
AERIAL
TIE AND BALLAST
SWITCH
MACARTHUR
SOUND LEVEL dB(A)
70
75
80
85
90
TUNNEL
TUNNEL
SWITCH
BRIDGE
SWITCH
ROCKRIDGE
AERIAL
TIE AND BALLAST
BRIDGE
BRIDGE
BRIDGE
BRIDGE
BRIDGE
SWITCH
BRIDGE
SWITCH
MACARTHUR
ACC/DEC
80 MPH
ACC/DEC
ALBANY
BERKELEY


SOUND LEVEL dB(A)
70
75
80
85
90
TUNNEL
TUNNEL
SWITCH
BRIDGE
SWITCH
ROCKRIDGE
AERIAL
TIE AND BALLAST
BRIDGE
BRIDGE
BRIDGE
BRIDGE
BRIDGE
SWITCH
BRIDGE
SWITCH
MACARTHUR
80 MPH
ACC/DEC
80 MPH
ACC/DEC

FREMONT LINE North

GENERALIZED BART WAYSIDE SOUND PROFILE

THE ENVIRONMENT PROJECT
BART IMPACT PROGRAM
FEBRUARY 1975

LEGEND

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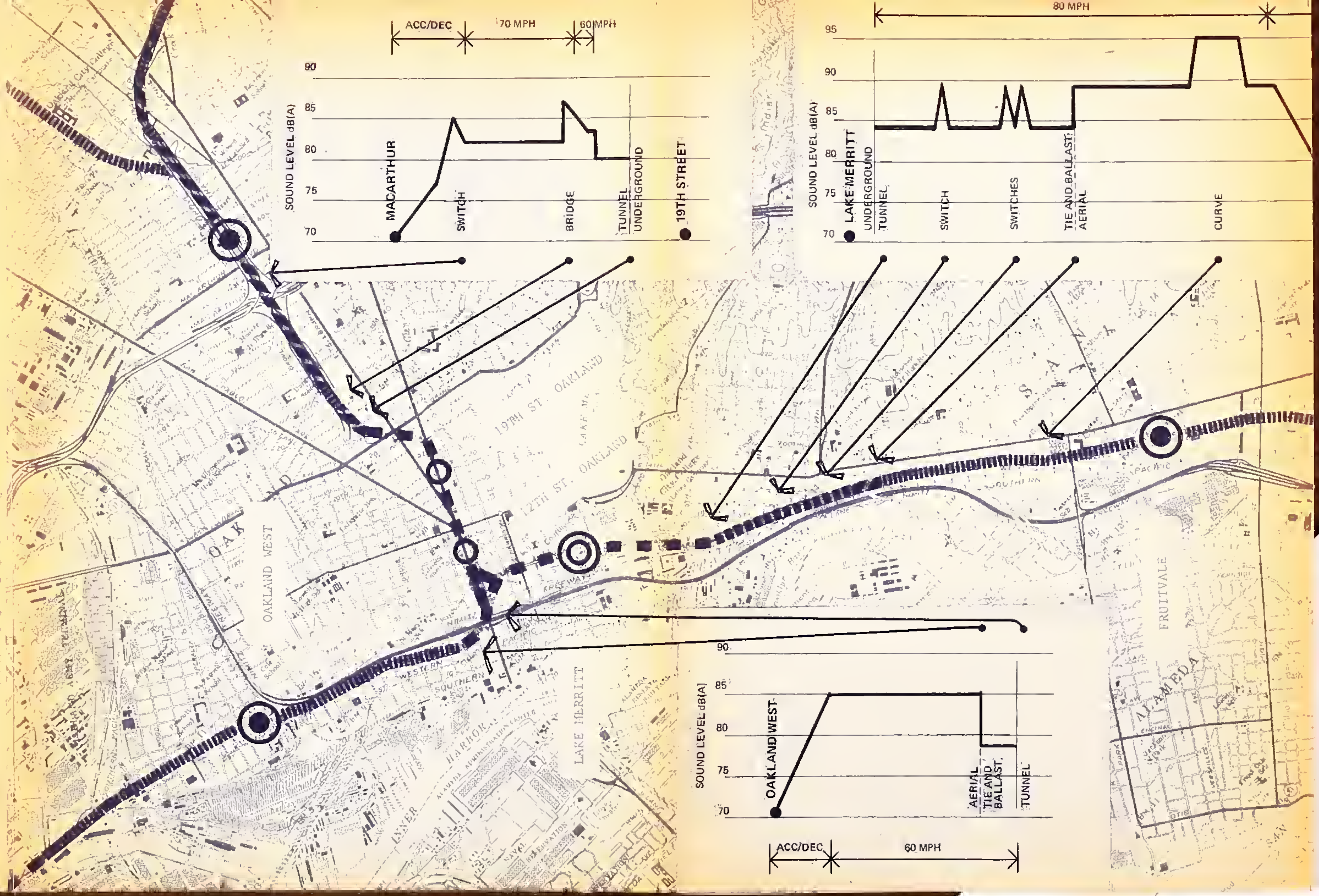
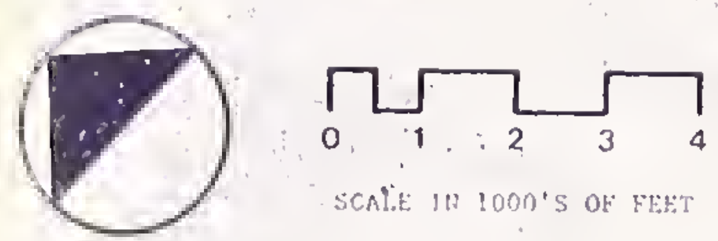
BART CONFIGURATION AND FACILITIES	
SUBWAY LINE	▬ ▬ ▬
AERIAL LINE	‖‖‖‖‖‖
LINE AT GRADE	▮▮▮▮▮▮
LINE ON BERM	▰▰▰
ABOVE GRADE STATION WITH PARKING LOT	◉
SUBWAY STATION WITHOUT PARKING LOT	○
SUBWAY STATION WITH PARKING LOT	◎
MAINTENANCE/STORAGE YARD	▨



80 MPH
ACC/DEC
80 MPH
ACC/DEC
80 MPH
ACC/DEC
80 MPH
ACC/DEC
SOUND LEVEL dB(A)
95
90
85
80
75
70
19TH STREET
LAKE MERRITT
UNDERGROUND TUNNEL
SWITCH
SWITCHES
TIE AND BALLAST AERIAL
CURVE
FRUITVALE
CURVE
SWITCHES
COLISEUM
CURVE
SAN LEANDRO
CURVE
SWITCHES
CURVE
BAY FAIR
FRUITVALE
COLISEUM
SAN LEANDRO
BAY FAIR
OAKLAND
ALAMEDA
SAN LEANDRO
ASHLAND
SAN LORENZO
SOUTHERN PACIFIC
Airport
ISLAND
90
85
80
75
70
SOUND LEVEL dB(A)
OAKLAND WEST
AERIAL
TIE AND BALLAST
TUNNEL
ACC/DEC
60 MPH

FREMONT LINE South

GENERALIZED BART WAYSIDE SOUND PROFILE



THE ENVIRONMENT PROJECT
BART IMPACT PROGRAM
FEBRUARY 1975

LEGEND

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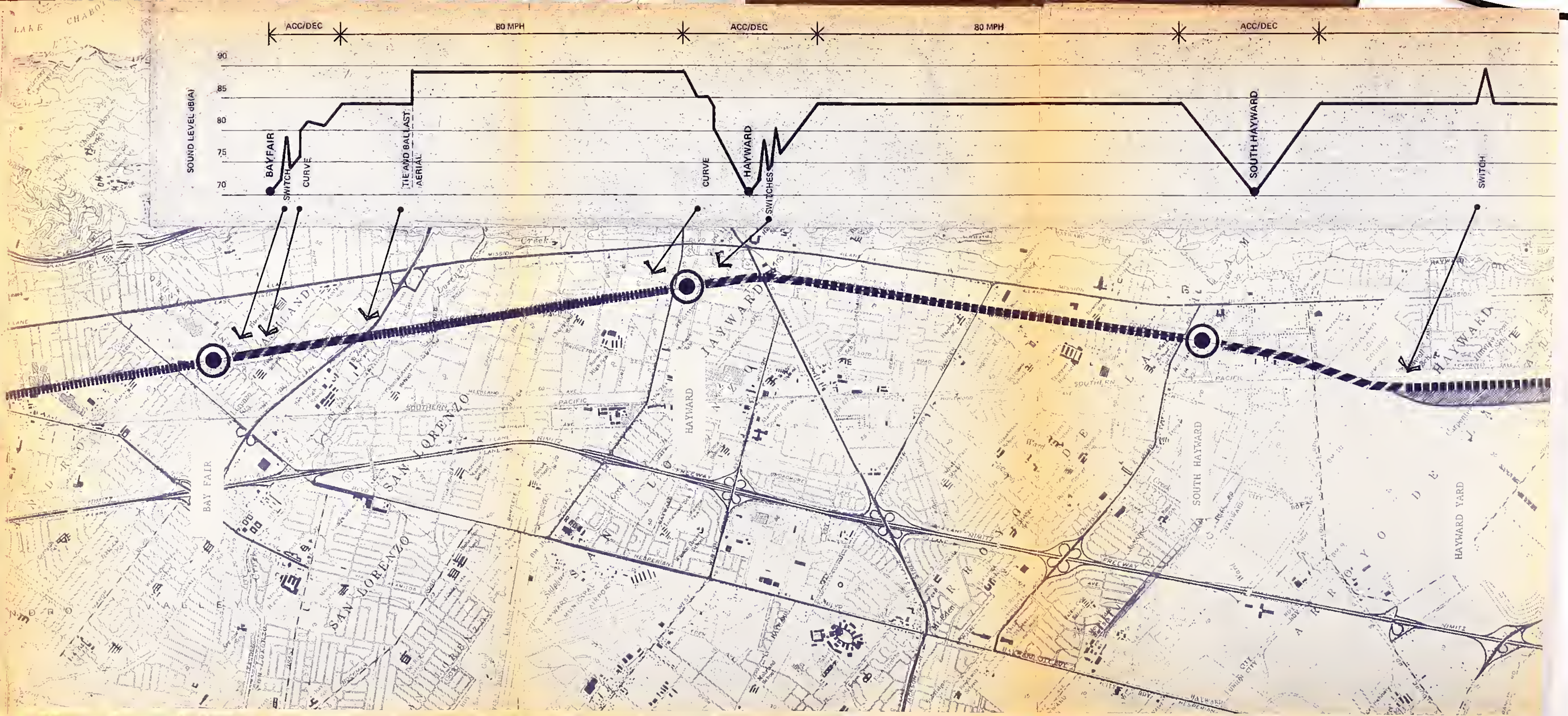
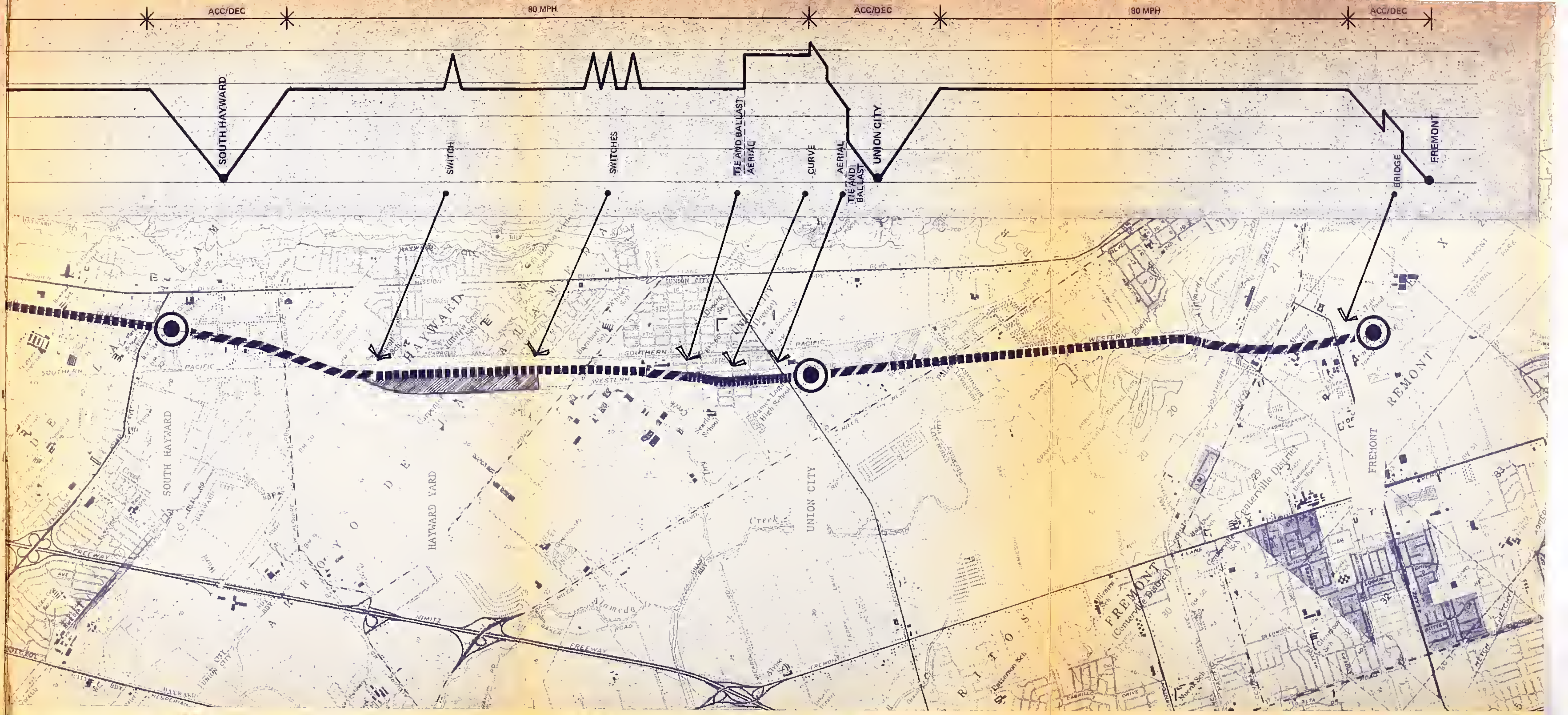
BART CONFIGURATION AND FACILITIES:

SUBWAY LINE	■ ■ ■
AERIAL LINE	❘❘❘❘❘❘❘❘❘❘❘❘
LINE AT GRADE	■■■■■■■
LINE ON BERM	▰▰▰▰
ABOVE GRADE STATION WITH PARKING LOT	◉
SUBWAY STATION WITHOUT PARKING LOT	○
SUBWAY STATION WITH PARKING LOT	◎
MAINTENANCE/STORAGE YARD	▨




ACC/DEC
80 MPH
ACC/DEC
80 MPH
ACC/DEC
SOUTH HAYWARD
SWITCH
SWITCHES
TIE AND BALLAST
AERIAL
CURVE
AERIAL
TIE AND BALLAST
UNION CITY
BRIDGE
FREMONT
HAYWARD
SOUTH HAYWARD
HAYWARD YARD
UNION CITY
FREMONT
FREMONT (Centerville District)
Centerville District
SOUTHERN PACIFIC
WESTERN PACIFIC
MISSION BLVD
NIMITZ FREEWAY
Alameda Creek